FINAL REPORT

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Project Title

Survey and Analysis of the Surficial Geology and Geophysics in the Pacific Marine Energy Center – South Energy Test Site area and Associated Cable Routes in the Vicinity of Seal Rock, Oregon

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Active Tectonics and Seafloor Mapping Laboratory Report 2014-03

Survey and Analysis of the Surficial Geology and Geophysics in the Pacific Marine Energy Center – South Energy Test Site area and Associated Cable Routes in the Vicinity of Seal Rock, Oregon

Executive Summary:

Geophysical surveys were conducted in June, 2014 in the area offshore of Seal Rock Oregon for the purpose of characterizing potential renewable energy installation sites and cable routes from the shore seaward to the South Energy Test Site (SETS). The geophysical surveys included 1) a high-resolution chirp multibeam sonar survey producing detailed bathymetry and backscatter coverage of the SETS area and potential cable routes; 2) A chirp sub bottom survey; 3) a boomer seismic survey; 4) a magnetic survey. The survey area can be characterized as a fold-thrust belt associated with the Cascadia Subduction Zone, and locally dominated by the N-S trending Seal Rock Anticline, which bring Miocene age rock to the surface in the inshore parts of the study area. The older rocks are intruded and modified by the Columbia River Basalt group flows that crop out onshore at Seal Rock. West of the Anticline, the western flank dips westward into a N-S trending basin bounded to the west by the Stonewall Anticline. The SETS area is located in the synclinal sedimentary basin that lies between these two major structures. The major rock outcropping in the area is the probable Miocene Astoria Formation/Nye Formation rocks of the Seal Rock Anticline. A pass through the anticline axis is formed by a paleo-channel likely linked to Beaver Creek. Initial desktop investigations suggested that the Beaver Creek paleo-channel might offer a burial option for a cable through the extensive rock outcrops of the exposed and eroded anticline. Initial sub bottom surveys suggested that this pass was very thinly covered with sand, likely insufficient for cable burial. Other routes were investigated south of the southward plunging anticline. These additional routes avoided the major hard-rock outcrops, but encountered outcrops of gravel and probable Pleistocene paleo landforms including paleo-channels, paleo topography both exposed and shallowly buried, and paleo subaerial aeolian dunes. Analysis of potential cable routes using the surface and subsurface geophysical data includes mapping of subsurface paleo-topographic and physiographic features to find the simplest routes to the SETS area.

Multibeam Survey:

The R2 Sonics 2024 chirp multi-frequency multibeam operates at selectable frequencies between 200-400 kHz, with 60 kHz bandwidth available, and generates up to 256 beams per ping at a rate of up to 60 Hz, covering an angular sector of up to 160°. The beam widths are 1° and 0. 5° at 400 kHz for along and across track beam widths respectively. The usable angular sector derived from internal quality flags generated by the sonar typically is limited 120° - 130°. Pulse length is variable from 33 usec to 300 usec. The quality of the beams may be influenced by vessel motion, surface noise, bottom hardness and roughness, and other factors. The 2024 is a stabilized system in both pitch and roll, that is, "beam steering" is employed to keep the fan array directed downward in all vessel attitudes. The R2S has a range resolution of less than 2 cm, and complies with IHO specification SP 44ED5 over its full depth range. A new area of multibeam data was collected at the SETS area and along an alternate cable route supplementing the existing multibeam data covering the proposed Airport, ODOT-Beaver Creek, and Driftwood Routes (Figure 1). Line spacing was arranged to provide 75 % overlap in bathymetry and backscatter. Cross lines along the survey were collected every 1,200 m. The cable route and site area survey covered 30.7 6km^2. Mean sounding density was greater than 6 soundings per m^2 at the SETS and greater than 14 soundings m^2 at along the routes. The additional route survey was done along the southwesterly parts of a revised cable route to help locate a viable route. Backscatter imagery is available for all survey areas (Figure 2).

Multibeam Data Acquisition and Processing

Multibeam data were collected using standard hydrographic protocols (NOAA Hydrographic Manual, 1976; NOAA 2009 Specification and Deliverables, 2009). Acquisition was done using the Hypack Hysweep & Survey 2013a acquisition package. The water column sound speed profile was regularly monitored using casts of a Seabird SBE 19 CTD. High frequency of sound speed profiling is highly beneficial to the ultimate quality of this nearshore survey, and was done every few lines at intervals of less than 4 hours. Continuous 'real-time" sound speed measurements were also made with a sound-speed probe at the R2S transducer head, a particularly important place to measure sound speed due to the physics of forming multiple sonar beams when using a flat transducer array.

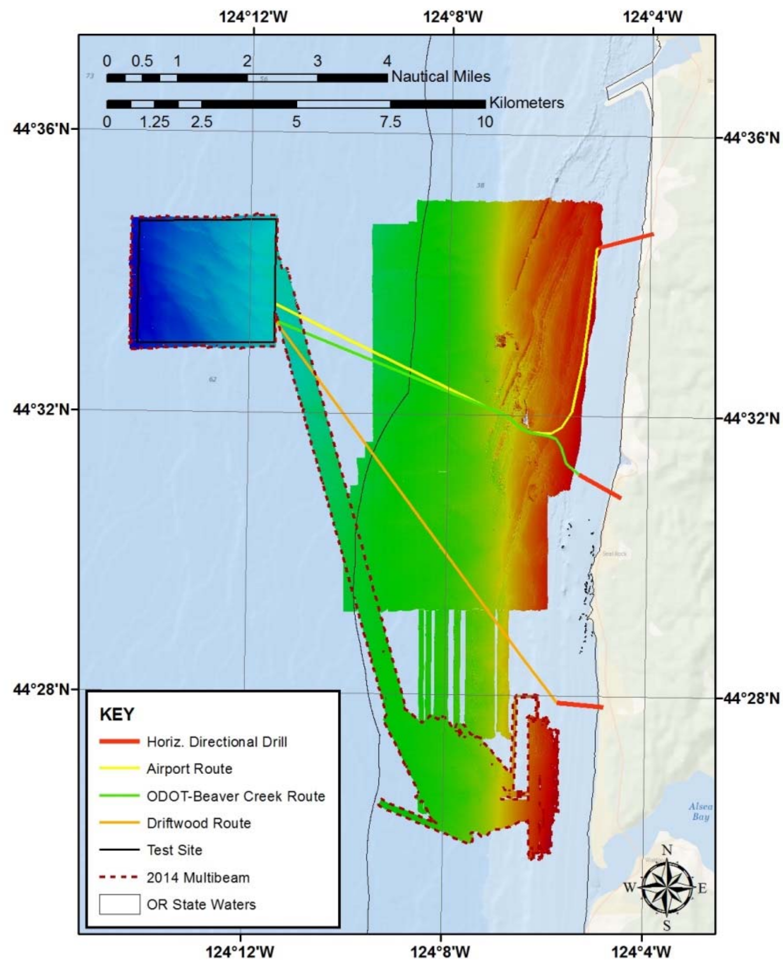


Figure 1. Multibeam bathymetry at the SETS area and along the proposed cable routes, new multibeam data collection area is indicated by the red dotted outline.

Vessel motion was measured and recorded using an Applanix POS/MV inertial measurement unit integrated with the R2 Sonics soar unit during all surveys. This system uses multiple GPS antennae arrayed on the vessel and an inertial system to produce Inertially-Aided Real-Time Kinematic (IARTK) attitude and position data utilizing L1 and L2 carrier phase measurements. The system is used for ships position, heading, and to determine roll, pitch, yaw attitude as well as heave. Antenna, Inertial Motion Unit (IMU) and sonar head positions were surveyed in place on the vessel for a previous project using a Total Station system. Small additional offsets for the sonar used in this project were measured and added to the Vessel Configuration file used in CARIS bathymetric processing. Additional positioning information is being collected with a NavCom StarFire SF 3050 GPS system. This system is a commercial satellite based differential system known as GSBAS (Global Satellite Based Augmentation System). This system provides positioning accuracy of ~ 10-20 cm horizontal, and 15-25 cm vertical worldwide (Dixon, 2006), and eliminates the need for land based base stations. The StarFire system also provides high precision vertical control that can be used for tide and heave corrections. Antenna and motion sensor positions and offsets as well as sonar head position and offsets have previously been surveyed for *R/V Pacific Storm*, providing a known measurement platform.

Datums

Final bathymetric sounding data was reduced to a tidal datum referenced to Mean Lower Low Water as specified by the NOAA 2009 Specification and Deliverables. This reduction is accomplished by using verified tidal observations (a NOAA product) from, at minimum, three nearby tide gauges to "correct" depth soundings by accounting for varying tidal stage or varying tidal magnitude during the survey.

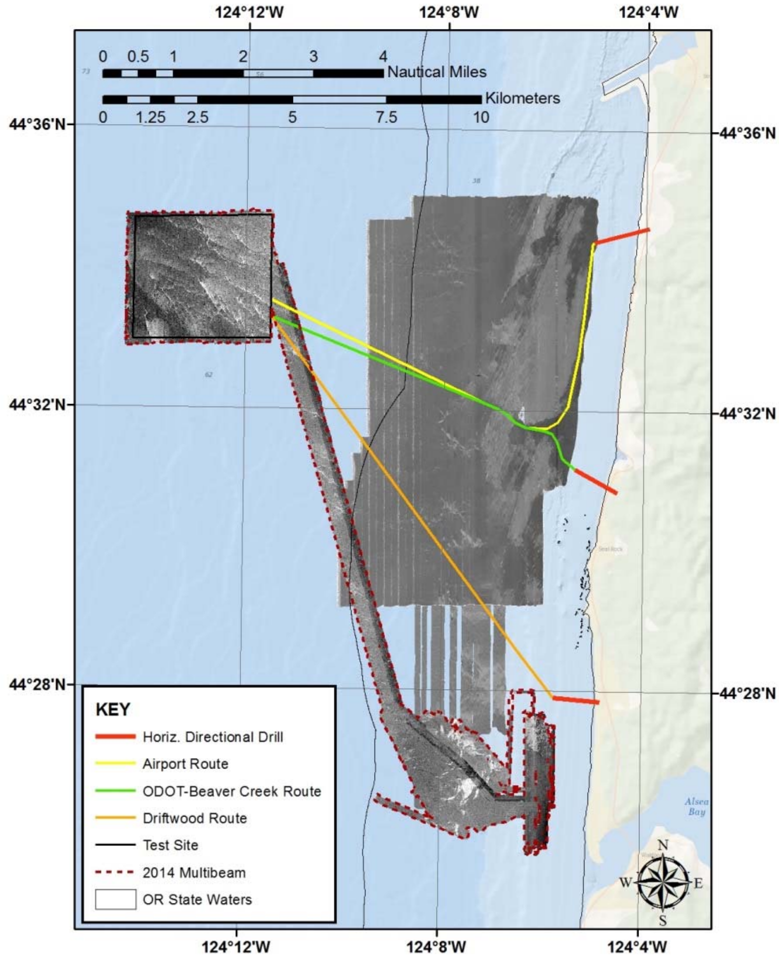


Figure 2. Multibeam backscatter imagery at the SETS Area and along the proposed cable routes.

Bathymetric data from all surveys was processed using CARIS HIPS and SIPS 8.1 data processing software. Backscatter mosaics were generated with QPS FM Geocoder Toolbox (FMGT 7.4.0d) software producing backscatter mosaics that incorporate geometric and beam pattern corrections, as well as removing artifacts of gain changes and topography during the survey.

Seismic Survey

We collected 254 line km of seismic profiles (Figure 3) using an Applied Acoustics AP1000 1.5 kJ "boomer" seismic system for imaging the shallow sedimentary section for geologic context, depth to basement, and existence of possible Columbia River Basalt (CRB) sills and other occurrences. Of particular interest are shallow occurrences of CRB at the inboard part of the Beaver Creek route, where exit of the directional drill hole is anticipated. The surface towed acoustic source was deployed by hand from the stern of the vessel. Augmenting the increased power and resolution of the AP1000 system is the use of a GeoEel® multichannel seismic streamer. We used a GeoEel digital 24 channel streamer with a group interval of 1.56 meters. This combination provides five times increase of signal to- noise versus single channel streamers. All data were recorded on a local laptop computer in SEGY format using Geometrics Seismic Controller software v. 5.61. The gear was supplied, mobilized and tested aboard *Pacific Storm* with seismic engineer Mike Barth of Subsea Systems. The system was run at a consistent power level of 300 Joules with gains fixed for all channels at 18dB. 300 MS of record were acquired for all lines. Channels 3 and 9 were recorded separately from the main SEGY datafiles of all channels for use as field monitor records. Channel 9 was used for field processing using SeiSee v. 2.19.2. This software allows viewing and basic processing if single channel data. The data were band pass filtered with band settings of F1=90 Hz, F2=400 Hz, F3=500 Hz, F4=600 Hz for field interpretation. Typical subsurface penetration with these settings was ~ 10-30 m. Marine mammal protocols were used, with marine mammal observers in the wheelhouse at all times, with all lines shot during daylight hours. No encounters with marine mammals occurred during the survey that required shutdown.

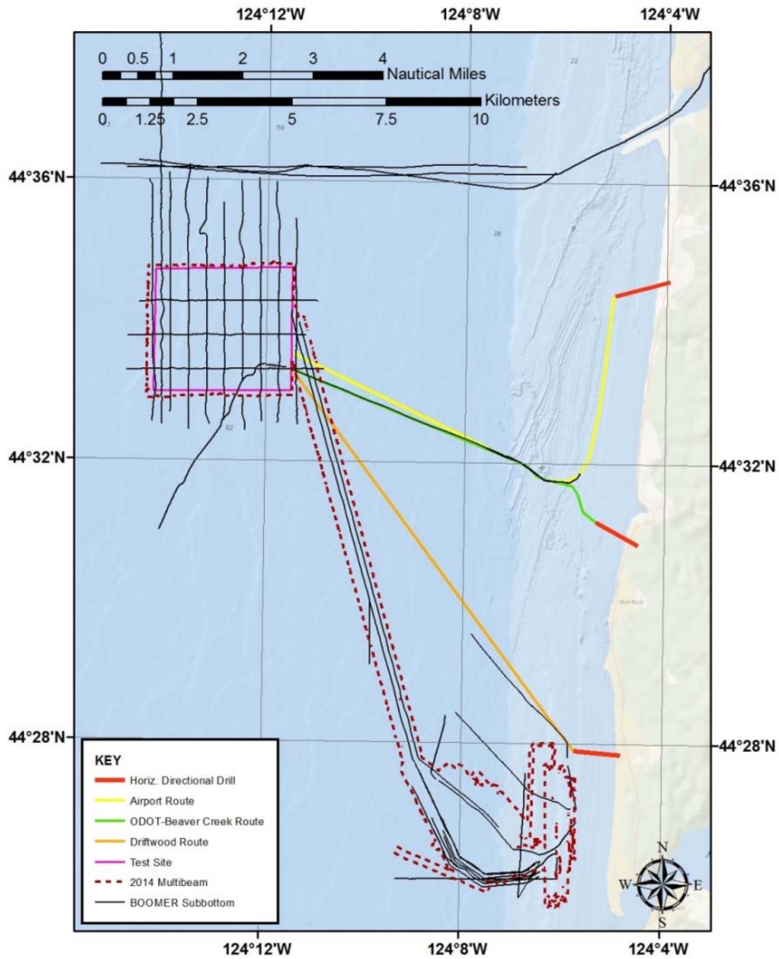


Figure 3. Boomer subbottom profile tracklines along proposed and alternate cable routes and at the SETS area.

Chirp Sub Bottom Survey and Processing

We collected 330 line km of Chirp data (Figure 4) along the potential cable routes using an Edgetech 512i sub bottom system to image the uppermost few meters at the highest possible resolution. Chirp has the advantage over continuous wave (CW) signals in that, properly applied, chirp signals can produce higher resolutions with lower noise levels than their CW counterparts. For FM chirp data, the frequency of the tone-burst varies linearly within the pulse itself which allows for higher resolution than a signal with a single frequency would have. Theoretical resolutions of 7-9 cm are possible, and in practice are typically on the order of 20-30 cm depending on the impedance contrast of the subsurface beds, sea conditions, water depth (due to beam angle of the sonar insonifying a larger footprint) and other factors. Line spacing was between 150 – 250 m in the SETS area box, and 100 m for the route survey lines. The Chirp data were collected with a bandwidth of 0.7-6 kHz at a ping rate of 2 Hz. Power and gains were set as required for best performance with variable substrate, water depth and sea state. The Chirp dataset was processed with Sioseis (Henkart, 2006) to mute the water column, remove heave, and bandpass filtered for imaging of the shallow subsurface.

Magnetic Survey

A total field magnetometer was towed for all boomer seismic operations during the survey, and was used at night when survey operations were shut down to complete the magnetic survey. The magnetometer was a Marine Magnetics SeaSpy Overhauser sensor magnetometer with a pressure depth sensor. The magnetometer was towed with a layback of approximately 50 m from the stern of the vessel. SeaSPY Overhauser magnetometer sensors can produce clear and strong proton precession signals using 1-2W of power with sensitivity that is one to two orders of magnitude better. Another benefit of the Overhauser effect is that polarization power is applied at a frequency that is far out of the bandwidth of the precession signal. Therefore, the sensor can be polarized in tandem with precession signal measurement. This effectively doubles the amount of information available to the magnetometer, allowing faster sampling rates than standard proton magnetometers. Since Overhauser magnetometers measure the same proton-resonance spectral line as standard proton magnetometers, they exhibit the same excellent accuracy and long-term stability characteristics. Magnetic data was collected at a ~ 2 Hz sample rate simultaneously with seismic acquisition. Testing of the sensitivity of the magnetometer to the sound source from the boomer system shown no sensitivity to the ~ 2 Hz boomer source. The magnetometer was towed off the starboard quarter, the boomer source from the port quarter to maximize separation.

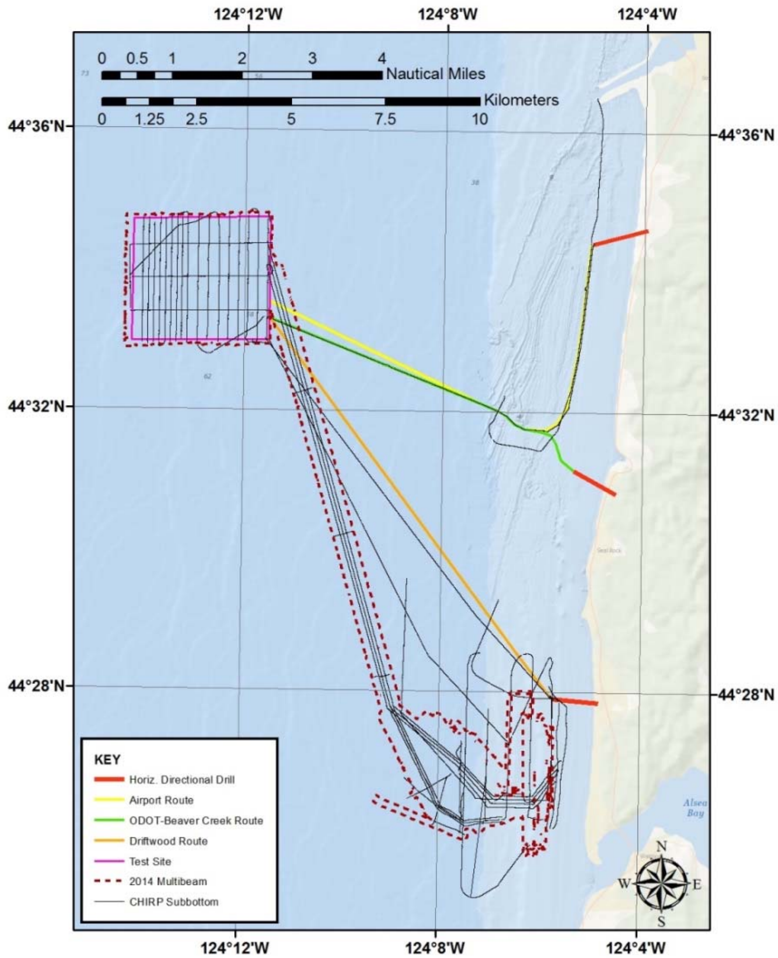


Figure 4. CHIRP subbottom profile tracklines along proposed and alternate cable routes and at the SETS area.

It was determined that local magnetic corrections via a local base station were not required for this survey as the goals were simply to identify magnetic rock bodies or metallic objects that would pose hazards along the cable route. The diurnal variation was removed using the regional base station data from the station at Fresno, CA or Victoria, BC Canada. The magnetometer was towed over and near several known magnetic sources including buoys and buried cable in and near Yaquina Bay to verify normal operation. A number of magnetic objects were found just outside Yaquina Bay during testing that were thought by the ship's crew to be the remains of the fishing vessel *Chevelle*, known to have sunk in approximately that location.

The SeaSpy requires synchronization of the magnetometer clock with GPS timing, and the automatic sync was found to be inoperative while at sea. A procedure to work around this was developed and manual synchronization was done at each startup of the system. NOTE: analysis of the data from the magnetic survey is still underway and results will be included in the next draft of this report.

Setting: Regional Geology

Interpretation of new and existing data shown in this report requires a regional geologic context. Fluctuating sea level, river sedimentation, sediment transport under gravity and wave loading, and the complex and active fault systems in the project area are the major drivers for surficial sediments. The Cascadia Subduction Zone consists of two small plates, the Gorda, and Juan de Fuca (JDF), subducting to the northeast beneath the North American plate (NOAM). The subduction system is bounded to the north and south by triple junctions and includes the smaller Explorer plate to the north, which may not be presently subducting (Rohr and Furlong, 1995). JDF-NOAM convergence is estimated as 40 mm/yr., directed 062° at 45° N. along the deformation front (rotation poles of DeMets et al., 1990). No active arc-parallel faults equivalent to the Japanese Median Tectonic Line (MTL) or Great Sumatran fault have been identified onshore in Cascadia. Snavely (1987) inferred that the Fulmar fault, a north-striking dextral strike-slip fault, offsets the continental slope and outer shelf in Oregon by about 200 km, and attributed an abrupt truncation of the basaltic Siletzia terrane to this fault. The Fulmar fault exhibits small offsets of Quaternary strata in southern Oregon, but was mainly active in the Eocene (Snavely, 1987). Paleomagnetically determined clockwise rotations of coastal basalts in Oregon and Washington suggest that a process of dextral shear of the forearc has operated throughout the Tertiary. Miocene (12-15 Ma) Columbia River Basalts in western Oregon are rotated 10-30° clockwise, and Eocene Siletz River Volcanics rotated up to 90° clockwise (Wells and Heller, 1988; England and Wells, 1991). Mechanisms proposed to explain these rotations include microplate rotation during terrane accretion, basin and range extension, distributed small block rotation, or a combination (see Wells and Heller, 1988 for summary).

The Quaternary portion of the accretionary wedge is widest off the Washington and northern Oregon margins, coincident with the accretion of the thick Pleistocene Astoria and Nitinat Fans (Carlson and Nelson, 1987), and narrows to the south. The active accretionary thrust faults and folds of the lower slope are characterized by mostly landward vergent (LV) thrusts on the Washington and northern Oregon margins and seaward vergent (SV) thrusts on the central and southern Oregon margin (Mackay et al., 1992; Seely, 1977; Goldfinger et al., 1992). Virtually all of the incoming section in the LV province is accreted to the margin above a deep décollement, whereas a shallower décollement in the seaward vergent portion of the margin results in accretion of the upper two-thirds of the incoming stratigraphic section and subduction and/or underplating of the lower one-third (Mackay et al., 1992). In addition to the SV and LV thrust faults and folds that comprise the Cascadia accretionary wedge, nine WNW-striking left- lateral strike slip faults (Goldfinger et al., 1997) also cut across the lower slope of the wedge. These faults form in the lower plate as a result of dextral shear of the forearc, due to the oblique subduction, and propagate upward into the accretionary wedge through time. The outermost accretionary wedge abuts a steep slope break that separates it from the Eocene oceanic basalt Siletz terrane that underlies the continental shelf off the central Oregon to southern Washington margins (Snavely, 1987; Trehu et al., 1994). Above this oceanic basement terrane is a modestly deformed Eocene through Holocene forearc basin sequence (Snavely, 1987; McNeill et al., 2000).

Structural geology of the Cascadia continental shelf (generally < 200 m depth) and stratigraphy has been interpreted by Snavely (1987), Niem et al. (1990), Goldfinger (1994; 1997), McNeill et al. (1999) and McCrory et al. (2002). The Oregon continental shelf was subjected to multiple Pleistocene transgressive/regressive cycles during the sea-level fluctuations caused by glacial advance and retreat. The last transgressive/regressive cycle left a widespread unconformity over which a thin Holocene sequence of transgressive sand and gravel was deposited on the middle to inner shelf, and a hemipelagic mud deposited on the middle to outer shelf (Kulm et al., 1975; Peterson et al., 1984). The age of the underlying strata ranges from Pleistocene (conformable in some locations on the middle to outer shelf) to Eocene and older on the southern Oregon inner shelf (Kulm and Fowler, 1974). This unconformity represents a relatively low-relief and generally seaward-dipping surface, and thus serves as an effective strain marker for latest Pleistocene and Holocene deformation. This erosional event is time-transgressive over the shelf. The last sea-level minimum of 110-130 m below modern sea-level occurred approximately 20,000 -22,000 years ago (Stanford et al., 2011), with sea-level rising to within a few meters of present level by about 7,000 years ago (Curray, 1965; Blackwelder et al., 1979; Chappel and Shackleton, 1986; Fairbanks, 1989; Matthews, 1990; Stanford et al., 2011). Thus tectonic activity that deforms this surface has a maximum age of about 22,000 years. Deformation of the Holocene shelf sand or mud on the inner shelf (< 40m) has a maximum age of about 9,000 years. Deformation of these sediments on the inner shelf is less common, and more difficult to detect, as water depths less than about 150 m are subject to active erosion and sediment transport by bottom currents and storm waves (Komar et al., 1972). In some areas of the inner shelf where sediment supply is low, recent sediments are thin and patchy or altogether absent. Deformation mapped in these older rocks is difficult to evaluate without younger sediments to reveal young offsets, however faults can be evaluated in terms of late Quaternary deformation by satisfying one of several possible criteria: 1) The fault deforms surficial materials; 2) The fault can be traced seaward into deep enough water that a Holocene scarp in unconsolidated sand or mud is preserved along the same structure; 3) the fault can be correlated to a known onshore fault that offsets late Quaternary deposits.

Structure of the Central Oregon Continental Shelf

On the middle to inner shelf (< 80 m) deformation rates are generally slower than on the accretionary wedge, and the interplay between tectonics and sediment transport and erosion is more important. Deformation on the continental slope steepens the bathymetry creating a topography where slope failures may expose rocky stratigraphy. On the continental shelf, a relatively flat erosional feature, process that expose or cover rocky features may be driven by tectonic, sedimentary, erosional, or some combination of each process.

The nearshore structure is dominated by folds and faults related to Miocene and younger compression along the Cascadia subduction plate boundary. Goldfinger (1994) mapped two sets of Neogene through Holocene structures. The older structures have NNW-NNE trends and are exposed in nearshore reefs such as the Seal Rock reef, Stonewall Bank reef (Yeats et al., 1998), Siletz Reef, Nehalem Bank, and Heceta Bank. The seafloor expression of these reefs is commonly exposed and eroded strike ridges sub-parallel to the fold axes. These strike ridges are generally composed of probable Miocene-Pliocene Astoria formation units of siltstones and sandstones and are resistant enough to erosion to exhibit emergent strike ridges. Further offshore, structures evident at the surface and near subsurface are NW trending folds and associated faults intersect the older folds at high angles. The relationship between the younger and older folds is not completely clear. It may be that the older folds have been rotated through time (see Wells, 1990) and are beginning to be overprinted by younger structures oriented normal to modern convergence as shown in Goldfinger et al. (1994; 1997). Both older and younger structures are deforming the modern sea floor as folding continues to deform the modern and relict Pleistocene wave cut platforms. The deformation commonly is of the form of numerous flexural slip faults (Yeats, 1986). These shallowly rooted faults invert the topography of the local seafloor as the synclinal axes are uplifted through bedding plane faulting (Figure 5). The recent sub bottom and boomer surveys show that many of these faults are active, deforming the modern seafloor and transgressive gravel layer. Typical offsets are ~ 1-2 meters. If the deformed surface is assumed to be completely eroded and ~ 15,000-18,000 years old, corresponding to the Last Glacial Maximum (LGM) and rapid transgressive phase, the slip rates of these faults are on the order of 0.05-0.13 mm/yr. Slip rates would be lower in the event of some offset surviving the post LGM transgression. Numerous faults of this type are in the study area.

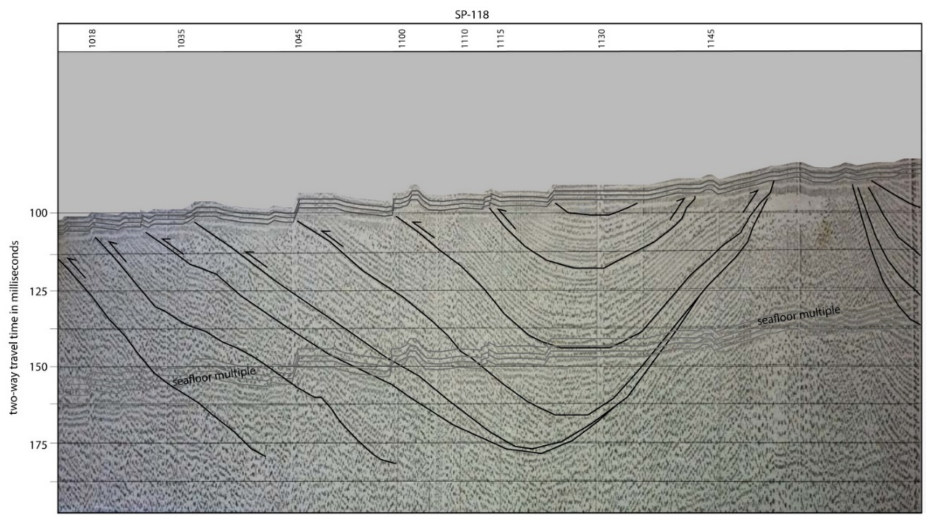


Figure 5. An example of typical flexural slip faulting style ubiquitous on the mid to inner shelf in the study area
Continued folding after the last glacial maximum (LGM) regression/transgression deforms the modern seafloor and creates a topographic inversion (syncline axis is up rather than down). This topographic inversion is important because bathymetric and structural maps cannot always be used directly to infer the locations of sedimentary basins. Image is a seismic reflection sparker profile from the 1960's (SP-118, unpublished at OSU).

The erosion surface is relatively rough topography in the shallow subsurface that comprises buried channels and other subaerial erosion features such as sea stacks, sea cliffs, exposed strike ridges and other features (Figure 6). A common feature of the erosion surface is lag gravel, typical of transgressive surfaces. This gravel is imaged in shallow seismic data, and is exposed in a number of "windows" through the overlying sand or gravel sheet that are clearly evident in the backscatter data. These windows are observed coast wide and have been termed "ripple scour depressions" (Cacchione et al., 1984; Thieler et al., 1998; Hallenbeck et al., 2012). Samples collected in 2009-2011 show mostly gravel and coarse sand in these windows on the central Oregon shelf. Other faults and intrusions are observed locally.

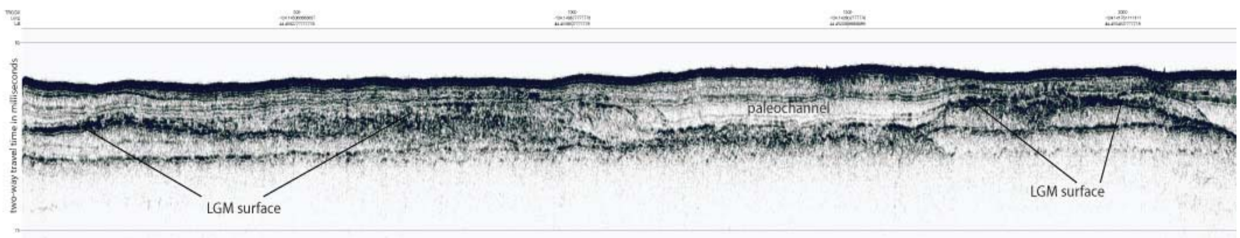


Figure 6. Chirp sub bottom profile in the vicinity of Newport, Oregon
Near surface sediments cover a strong reflector interpreted to be the last glacial maximum (LGM) erosion surface. This rough surface was the subaerial land surface during the last lowstand, and comprises subaerial erosion features, stream channels, and transgressive features such as sea stacks and paleo seacliffs. A paleo-channel is shown in this CHIRP sub-bottom profile image (OSU, Northwest National Marine Renewable Energy Center, unpublished data).

Structural or Wave Control of Ripple Scour Depressions?

Seafloor features called "rippled scour depressions" (RSDs) were first described on the inner continental shelf off northern California in the early 1980's (Cacchione, 1984). In the northern California examples, the fine-to-medium sand shelf surface of the inner shelf is interrupted by elongate depressions with low relief (< 1 m) extending shore-normal to slightly oblique in water depths from 20-70 m (Cacchione, 2005). Similar features have been mapped elsewhere (i.e. Trembanis et al., 2011). The northern California depressions vary widely from 50-500 m in width, have sharp sidewalls and have one wall marking a sharp contact between the fine to medium sand and the other less distinct and irregular. The coarse sand and gravel exposed in the depressions is arranged in ripples with crests aligned normal or slightly oblique to the sidewalls (Cacchione, 2005). The large ripples are thought to be generated by wave-induced bottom stresses during storms, and are commonly erased or reset during high wave episodes. Recent work has shown that ~ 3.6% of the shelf within California State waters are occupied by RSD's (Davis et al., 2012; Hallenbeck et al., 2012), and that there is an increased frequency of RSDs near rocky reefs. The RSDs thus comprise an important component of hard substrate in the California shelf.

Along the Oregon shelf, recent surveys including data from the Oregon State Waters Mapping Program (ORSWMP; e.g. Kane et al., 2011; Erhardt et al., 2011) show numerous depressions similar to those reported off Northern California. These depressions have been mapped as hard substrate, but were not explicitly distinguished from other hard substrates in the Oregon State Waters habitat maps. To date, we have not observed ripples in these depressions, which appear to be mostly coarse sand and gravel, supported by targeted grab sampling. Not enough data exist to show whether the sidewall sands interfinger with the gravels or are in sharp contact, but morphologically they appear sharp and otherwise similar to the Northern California examples. Many of the Oregon examples also lack a preferred trend relative to the coast or prevailing wind and wave environment as noted for the northern California examples. Given these differences, it remains unclear whether the Oregon depressions are the same as their Northern California counterparts.

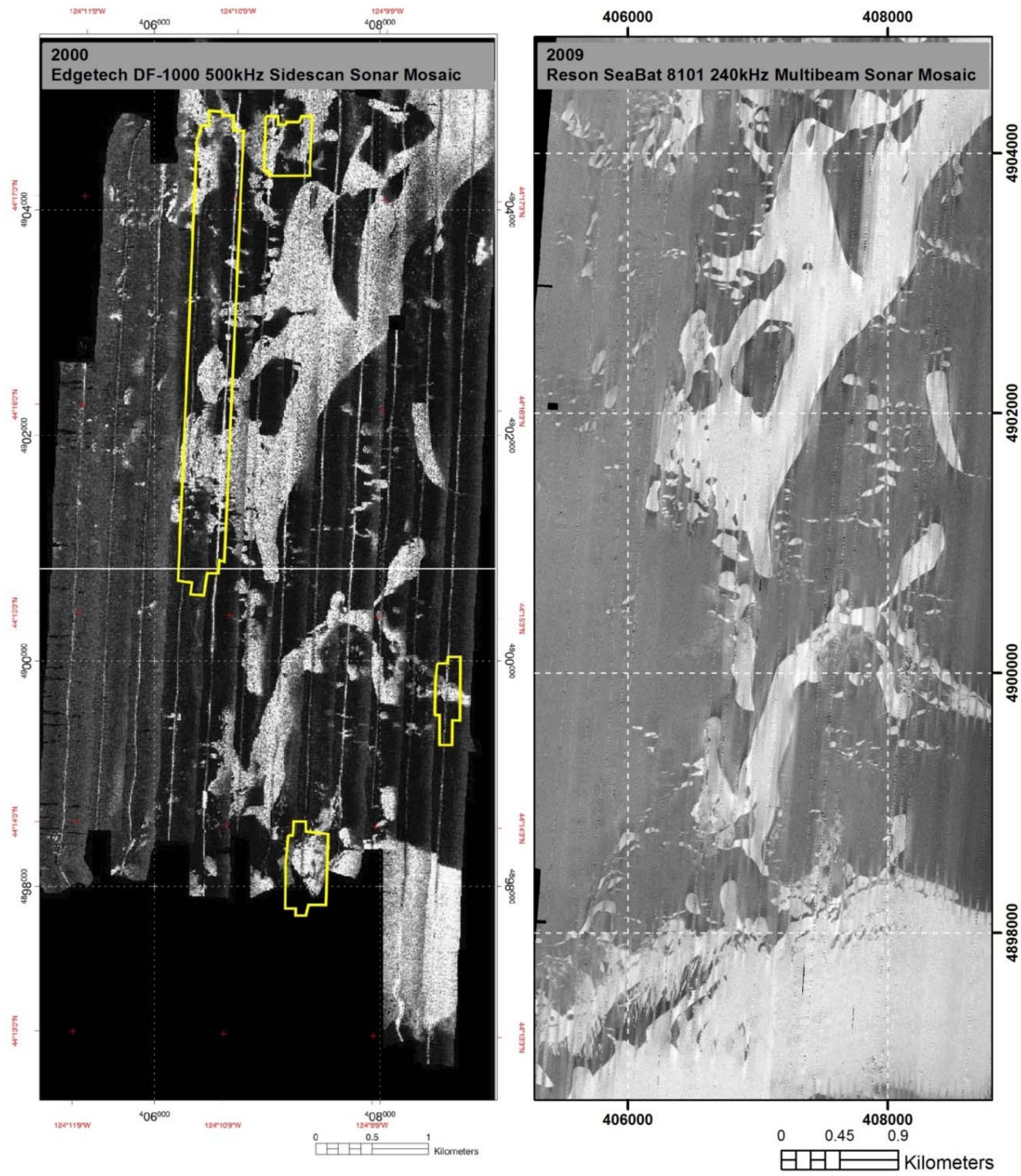


Figure 7. Repeat backscatter surveys (2000 left & 2009 right) at Cape Perpetua, Oregon
Repeat surveys spanning nine years show little if any change in scour depression location. Bright backscatter intensity areas in the northern and central portions of the imagery are known to be scour depressions from bathymetry and ROV observation. Backscatter image on left from Fox et al., 2004.

We note that in repeat surveys in the Cape Perpetua area (Figure 7), the depressions mapped in water depths of 45 m to 50 m in two surveys in 2000 and 2009, nine years apart show that the depressions are in the same positions at these two times, with very little change in morphology. We found this surprising given the interpretation of the northern California depressions as generated by storm waves. Thus the Oregon versions should probably not be termed “ripple scour depressions” as they are neither rippled, nor do they show clear evidence of scouring by waves as they may have remained fixed in position over time. We note that the Oregon depressions appear to have an association with shallow subsurface structure or topography, suggesting that they may be linked to these features. Although this study (and the Oregon State Waters Program) did not explicitly study these features, they are discussed in some detail in the Newport area in a subsequent section.

Temporal Change in Surface Sediments

Seabeds at water depths of less than about 150 m are subject to active erosion and sediment transport by bottom currents and storm waves (Komar et al., 1972). At depths greater than 150 m, only rare tsunami waves (down to ~ 450 m; Goldfinger et al., 2012) and potentially internal waves can externally disturb bottom sediments. Otherwise, processes are generally dominated by hemipelagic sedimentation, disturbance and slope failures related to tectonism and earthquakes (Goldfinger et al., 2012). On the inner shelf (< 40m) anecdotal information from local crab fishermen (Bob Eder, Ronald Briggs pers. comm.) suggests sand mobility is high in this region. Some crab fishermen, primarily in a depth range of ~7-30 m, use a “pot pump” to hydraulically pump out crab pots that have been buried during their deployment. Such burials can be up to a meter, and possibly more in rare cases. Our repeat bathymetric surveys at Redfish Rocks (southern Oregon coast, 30 m and shallower) in the summer of 2008 and late spring of 2009 (Amolo, 2010) support this level of sand mobilization between summer and winter months, where variability of 0-1.5 m is apparent (Figure 8). Greater mobility may exist in some areas, but no documentation that we are aware of exists for this. The lack of movement of the scour depressions in the Cape Perpetua area (Figure 7) suggest otherwise, however the repeated surveys were not exactly equivalent, the first being sidescan only with no bathymetric information.

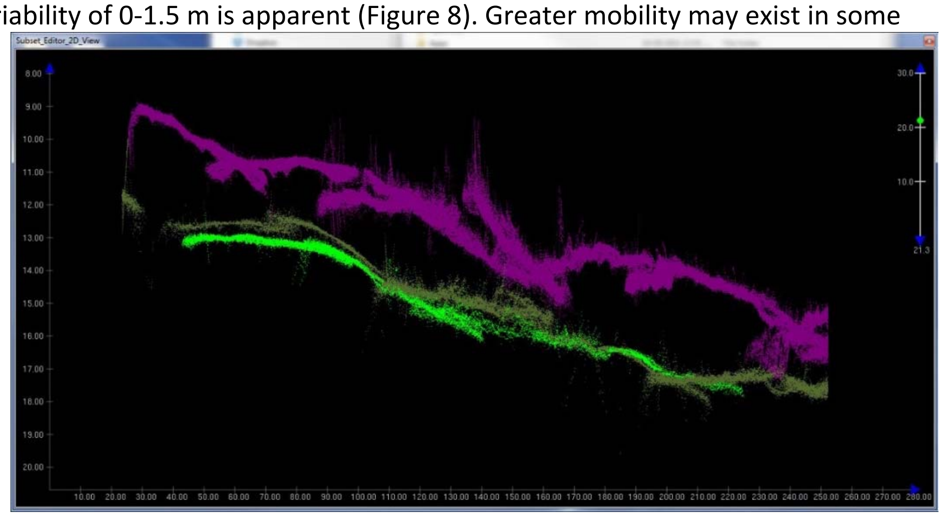


Figure 8. Vertical offset in repeat surveys at Redfish Rocks, Oregon. An approximate two meter offset is observed between the 2008 survey (green) and 2009 survey (purple) soundings at Redfish Rocks, Oregon. The offset is presumed to be caused by seasonal migration of nearshore sands. Data provided by the Port Orford Ocean Resources Team, Golden Marine Consulting, and Seavisual Inc.

Possible Methane Venting and Carbonate Deposition

Methane vents are common on active continental margins, and Cascadia is well known to have numerous such vents (Trehu et al., 1995; Suess et al., 2001; Johnson et al., 2003). The continental shelf of Oregon, at depths shallower than 160-200 m, is entirely above the gas hydrate stability zone (~ 550 m and deeper). Venting on the shelf therefore is not indicative of shallowly buried gas hydrates, but rather of direct venting of biogenic gas. Such venting occurs along fault zones, scarps from submarine landslides and other geologic features. On the shelf, such vents can appear at the surface venting through pits in the surface sands. Examples of methane vents are discussed in Johnson et al. (2003), Goldfinger et al. (1996) and many other resources. A byproduct of methane venting can be deposition of carbonates (Kulm and Suess, 1990). These carbonates are extremely hard rocks that are found widely scattered on the Oregon margin (Schroeder et al., 1987). Carbonate deposition related to venting is commonly imaged in backscatter and sidescan data given its high acoustic reflectivity, thus backscatter mosaics are effective tools for evaluating the potential occurrence of surficial carbonates. In the backscatter images of the shelf study sites, we observe few “pockmarks” which are the backscatter signature of gas venting and sometimes associated with carbonate rocks in deeper water. More details of the site specific geology are given in the site results sections below.

Interpreted Surficial Geology

A larger area than that discussed in this report was mapped in 2010 off Newport Oregon under a BOEM renewable energy project, and is briefly discussed here because of its general similarities to the SETS study. This mid-shelf soft sediment region was mapped in June of 2010 from the *R/V Pacific Storm* using a Reson 8101 (240 kHz) multibeam sonar (Figure 9 and Figure 10). The BOEM Newport study site covers a 12 km by 10 km area and abuts Oregon State Waters Mapping Program multibeam data to the east and Ocean Observing Initiative data to the west creating continuous data coverage from approximately 10 m water depth nearshore to 80 m water depth offshore. Box Core (n=25) and Shipek Grab (n=31) sampling was conducted in the Newport study site. Classified grain size information from the BOEM Box Cores and Shipek grab samples were used to map sedimentary habitats at Newport, OR. The surface lithology is primarily medium sand, with thin NW stringers of coarse sand (Figure 11). There is no rock outcrop at this site. As with Nehalem, and the SETS area a few kilometers to the south, this pervasive NW trending fabric of sand and high backscatter depressions has modest bathymetric expression.

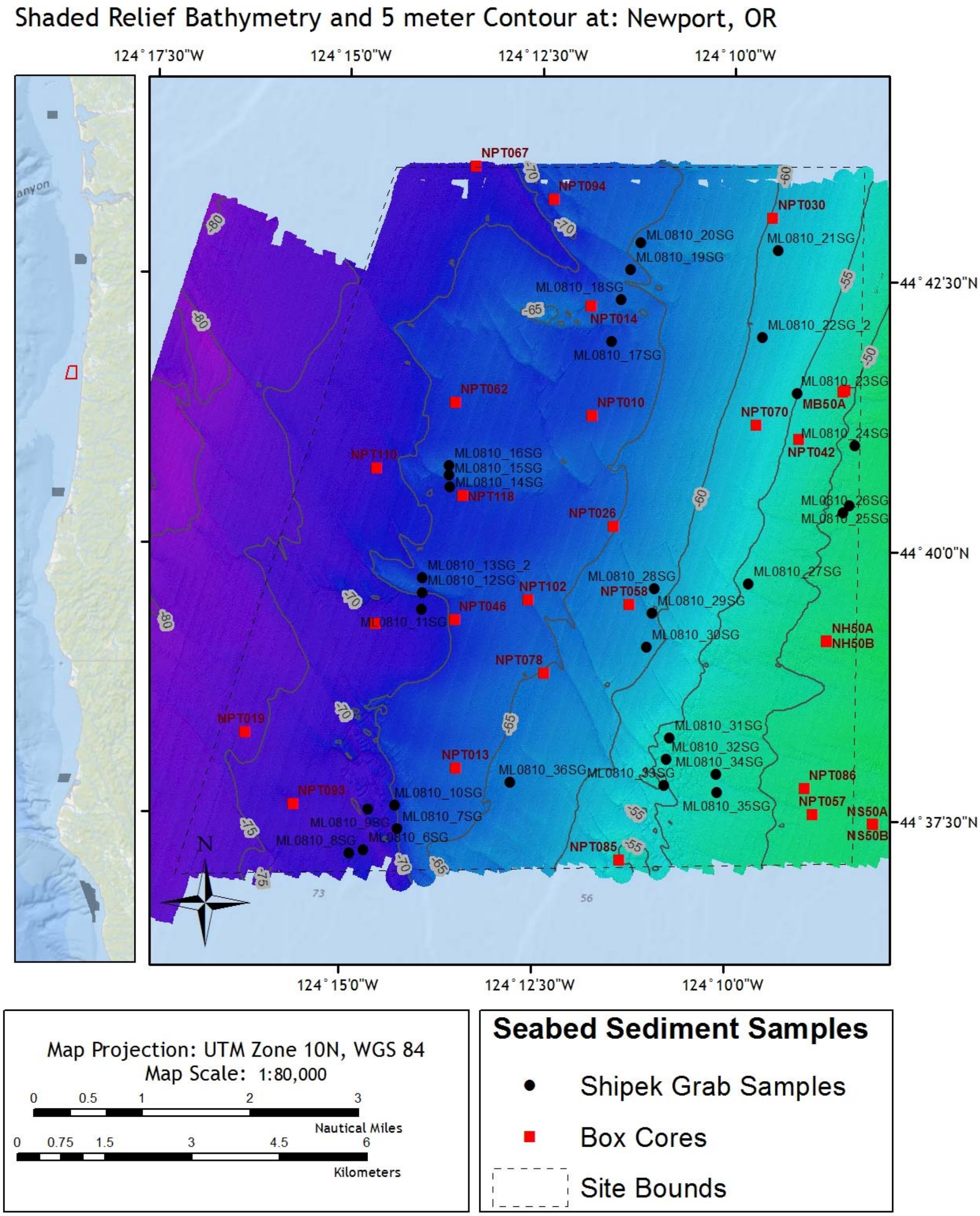


Figure 9. Color shaded-relief multibeam bathymetry data collected at Newport, OR
Sediment sample stations plotted over the Reson 8101 (240 kHz) multibeam bathymetry data.

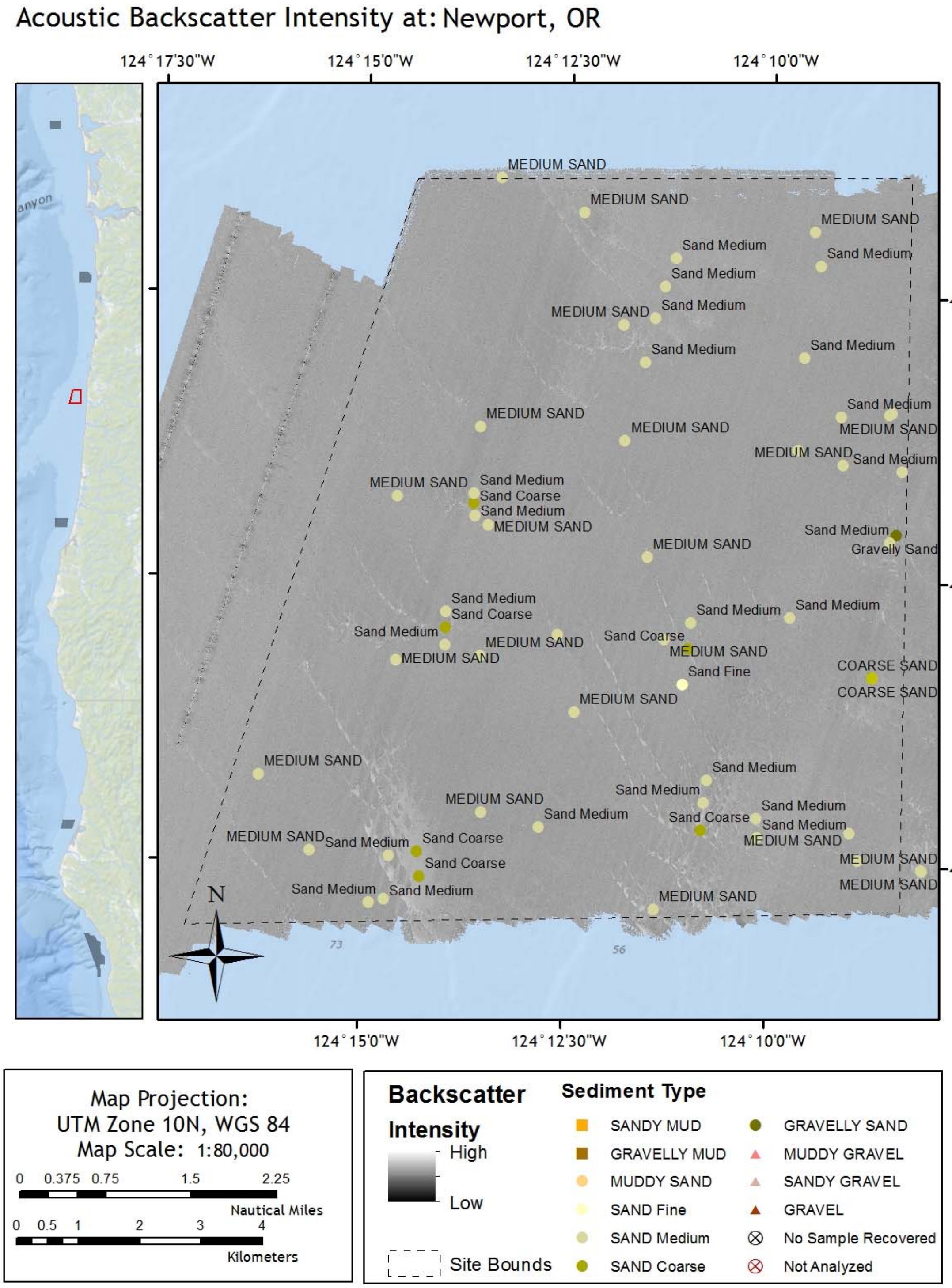


Figure 10. Multibeam backscatter data collected at Newport, OR.
Sediment textural classifications are plotted over the Reson 8101 (240 kHz) multibeam backscatter data.

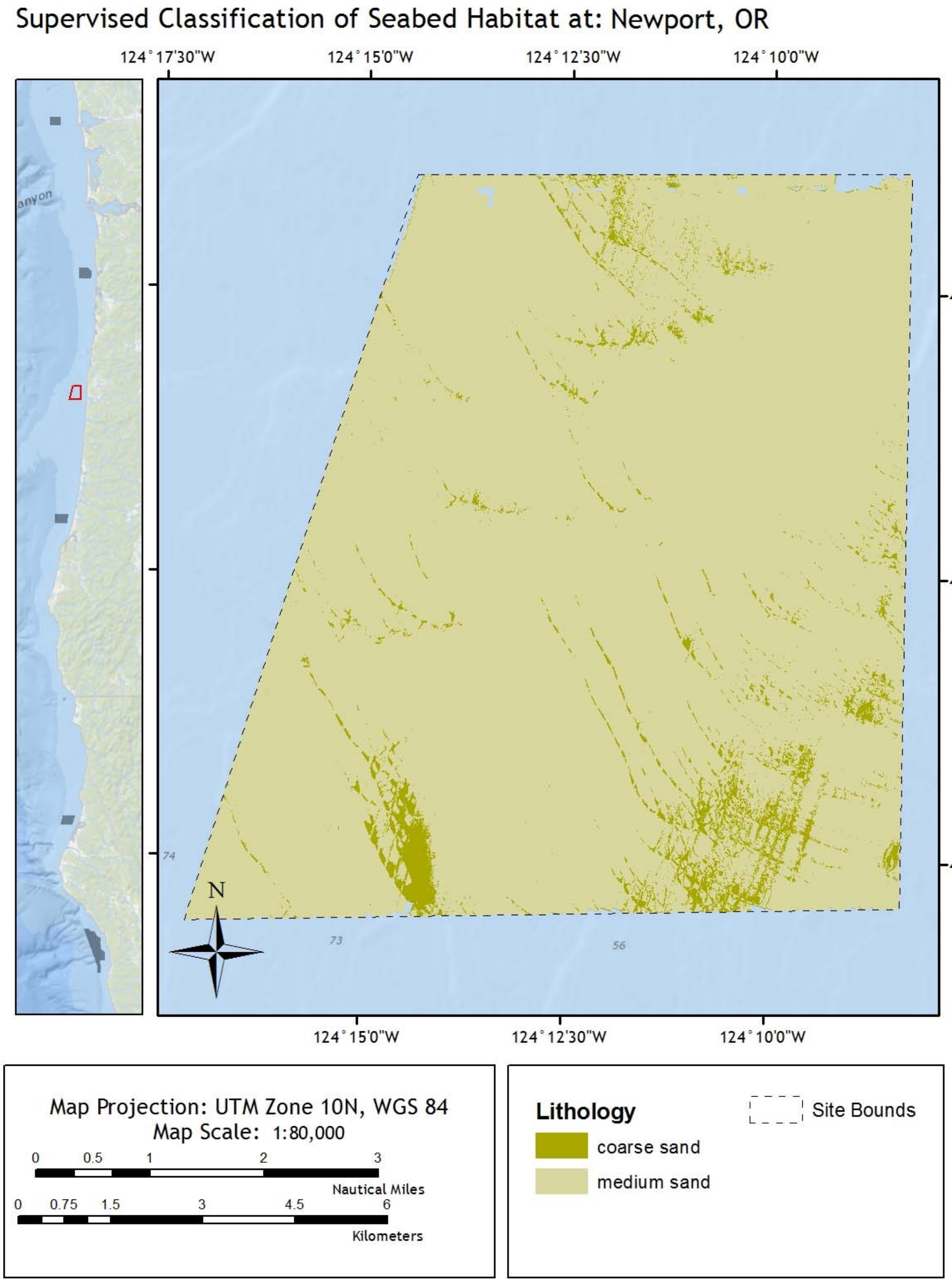


Figure 11. Seabed substrates at Newport, OR
Sediment classes are predicted by supervised classification of seabed samples and imagery, rocky relief classes are predicted by analysis of bathymetric data.

South Energy Test Site (SETS), OR

Figure 12 shows the SETS survey overview with bathymetric data overlain with tracklines from the boomer and CHIRP profiles. Figure 13 shows the SETS area, overlain with regional structural geologic interpretation of the major structures in the area based on industry and academic single channel sparker profiles, as well as industry multichannel profiles. The SETS area, and the BOEM site just to the north, lie in an active syncline between the Seal Rock anticline onshore to the east, and the Stonewall anticline just to the west (Yeats et al., 1998). These anticlines expose rocks of Miocene age (Relizian and Saucezian Stage faunal calls based on proprietary industry dart core data) equivalent to Astoria Formation units mapped onshore (Snavely et al., 1969). The crest to crest distance between the two anticlines is at least 25 km. This broad syncline has several active flexural slip faults on its western margin, and several down the west faults of unknown type on its eastern margin. Seafloor offsets on these faults indicate that they, and the underlying syncline, have been active in the Holocene. A prominent unconformity is apparent in the seismic profiles, which is also observed at a depth of 10-80 m in the 2014 boomer profiles. This unconformity separates two primary units with greater (lower) and lesser (upper) degrees of deformation.

Northwest Trending Bathymetric Features

We investigated the pervasive NW trending topographic features seen in Figure 14 to determine their origin and relationships to hard substrate as seen in the bathymetry and backscatter data (Figure 15). We initially thought that the features were likely structural, as they are pervasive through the area, extend well to the north through the BOEM study box and much further north along the Oregon inner shelf (limits are presently unknown). These features also lie at nearly right angles to the plate convergence direction, suggesting a potential link. However, they also lie at 50-70 degree angle to the major active structures shown in Figure 13, making a structural origin less than straightforward.

In Figure 16, we show one of the CHIRP profiles across the NW trending features, along with backscatter data for the same area. The low amplitude topographic highs correspond to the backscatter highs, which generally are strongest on the SW flanks of these features. The topographic highs are asymmetric, with steeper slopes to the southwest, and shallower slopes the NE. The backscatter data also follow this pattern, with high backscatter tracing the SW (steeper) flanks, and fading in intensity to the NE. The sub bottom image shows that the topographic highs generally do not correspond to faults as we had initially assumed. There as small diffractions in the data most likely related to steps in acoustic impedance (hard to soft) that extend downward, but are artifacts and not structures. We have not found any examples where these low amplitude asymmetric highs are linked to faulting. We also observe that the underlying unconformity is not deformed below these features, as one would expect if they were generated by faulting. There is however a slight mimicking of the upper topography that we interpret as velocity “pullup” and artifact of having more high velocity material overlying the topographic highs.

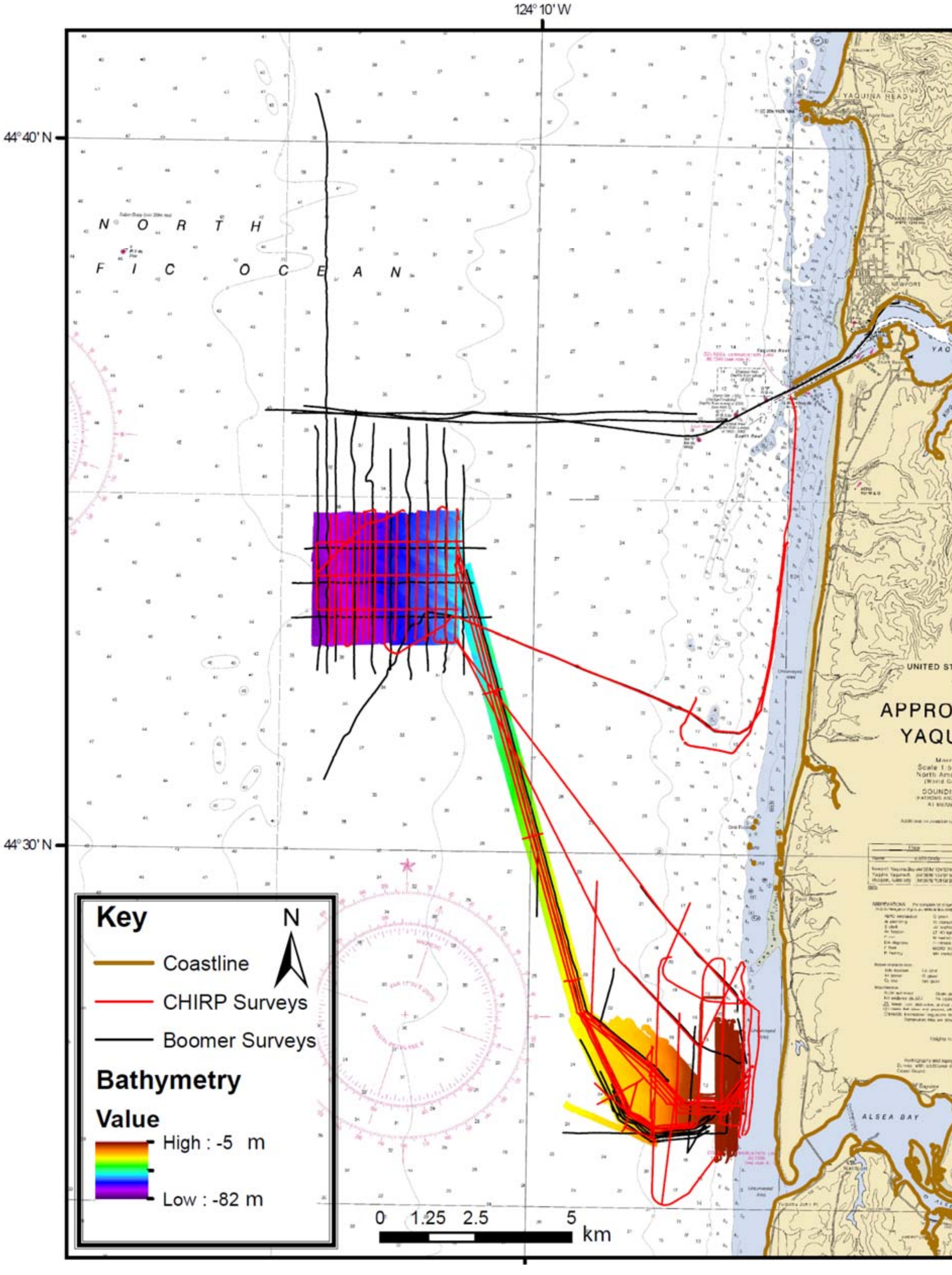


Figure 12. SETS area bathymetric data and geophysical tracklines near Seal Rock, OR

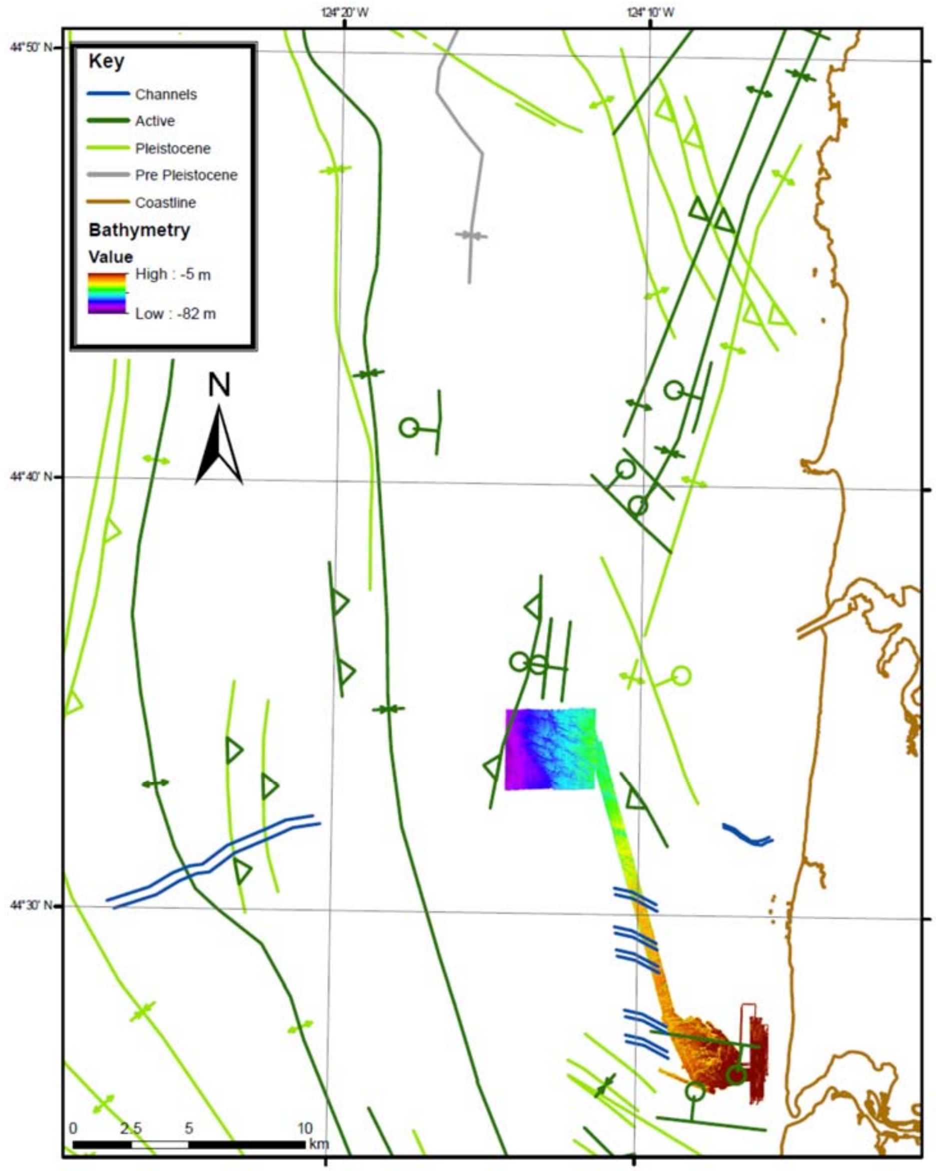


Figure 13. Major structures of the inner shelf off Newport, OR
SETS bathymetric data shown. SETS lies on the east flank of major syncline at center. NW trending bathymetric features in the SETS bathymetry (and BOEM Newport as well) cross the structural grain at an obtuse angle.

Examination of the CHIRP and boomer datasets reveals that the relationship between the topographic highs and the backscatter is very strong, and the lack of underlying structure is pervasive. The low amplitude topographic highs have wavelengths of 200-600 m, and are overlain by sub-parallel but smaller features that are generally similar, which we interpret as sand waves.

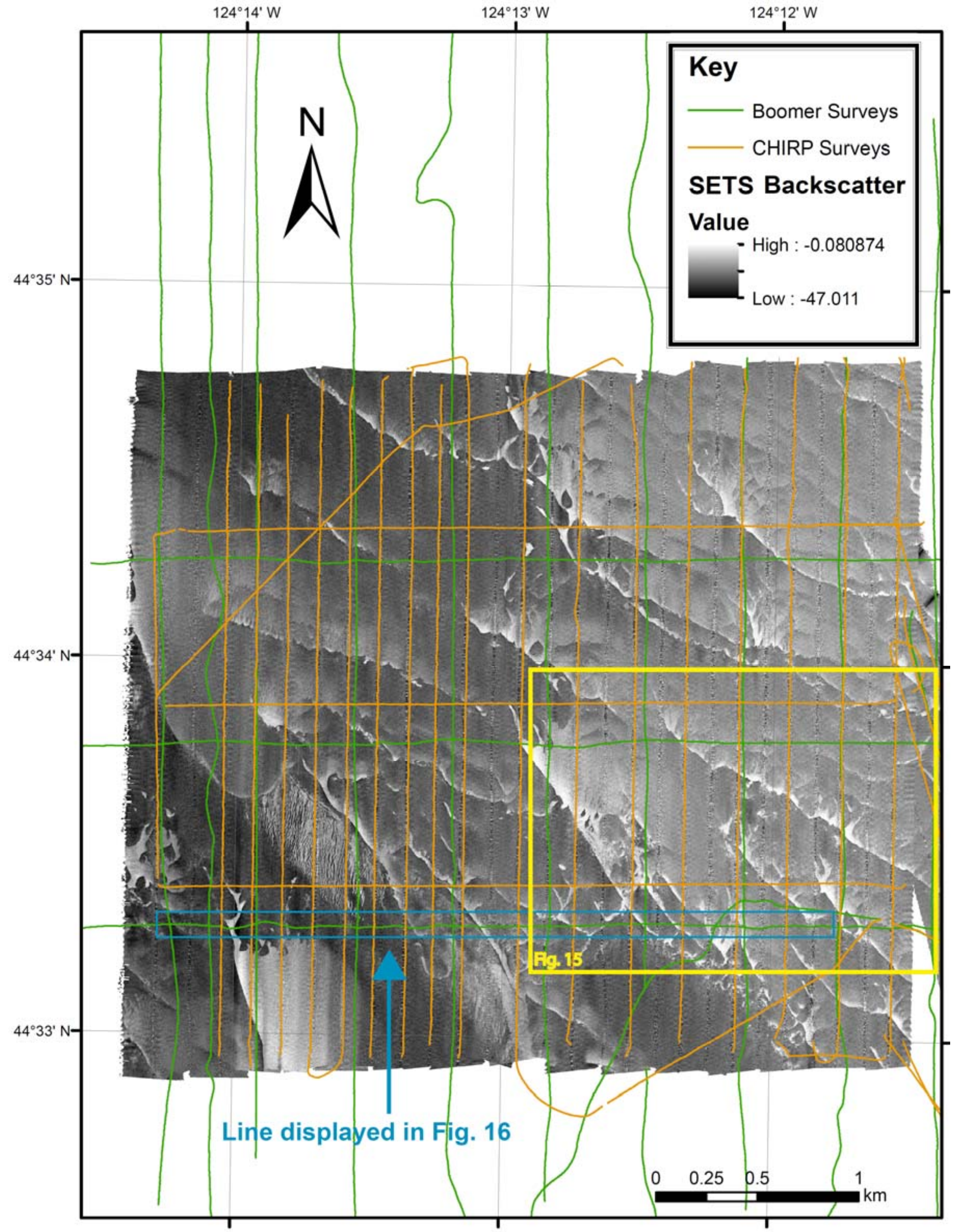
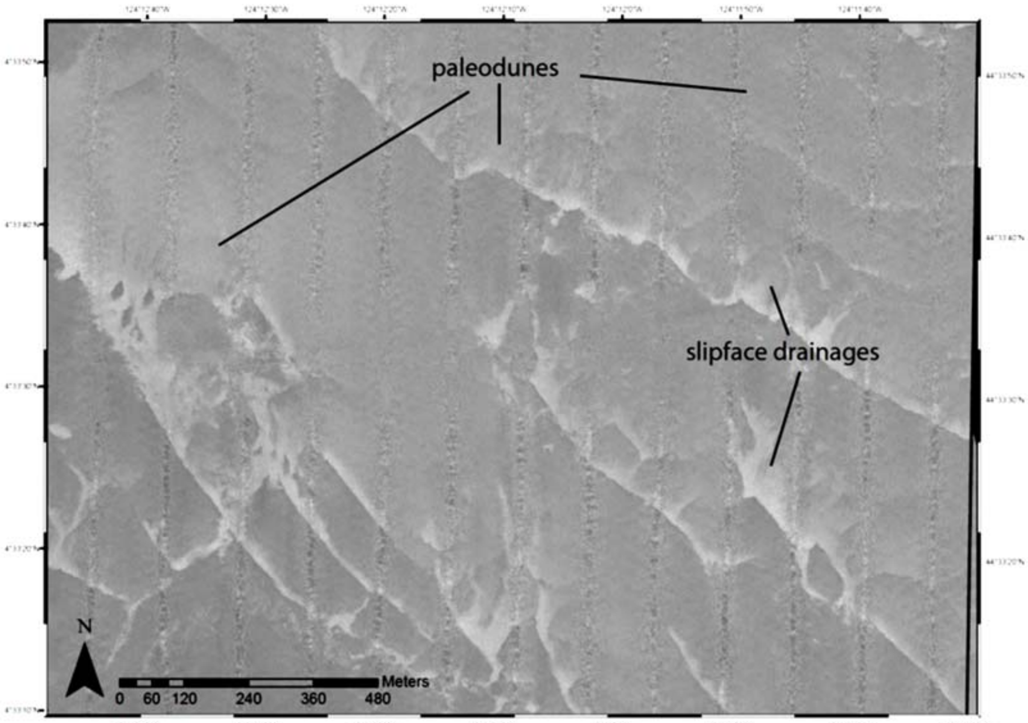


Figure 14. Backscatter data in the SETS area overlain with boomer and CHIRP sub bottom profile tracklines.
Pervasive NW trending features are shown, with high backscatter concentrated on the SW faces of the asymmetric features. Areas of Figure 15 and 16 are shown.



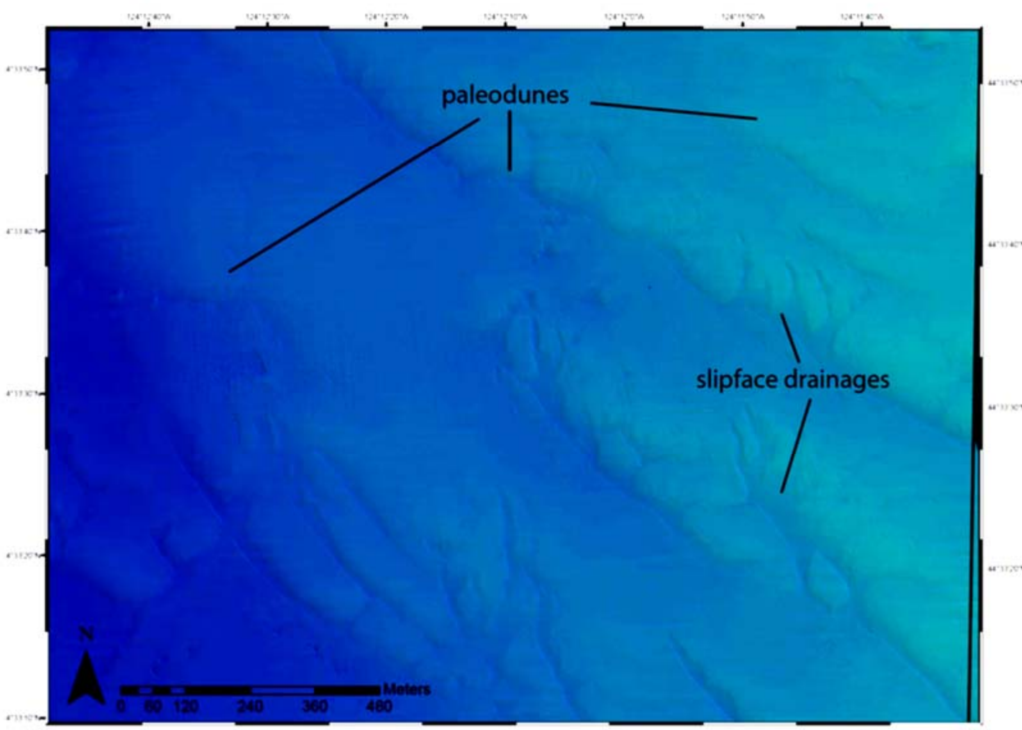


Figure 15. Backscatter (top) and shaded relief imagery of a part of the SETS area
NW trending asymmetric bathymetric features are shown in the seabed imagery. Steeper faces toward the SW. Scour depressions (high backscatter) form drainages, mostly on the steeper faces. Features are tentatively interpreted as subaerially formed paleo-dunes.

Looking closely at the backscatter and bathymetric data we see that the high backscatter areas are depressions as previously described, but also that they are closely related to the underlying low amplitude highs. Many of the high backscatter depressions form along the steeper SW flanks of the highs, and many also form dendritic drainages off these highs into the swales between them (Figure 15). The presence of drainage patterns like this suggest that the underlying features are long-lived enough that secondary erosion processes are modifying them significantly. This also provides an explanation for the lack of temporal movement of these high backscatter features. At least within the SETS study area, and perhaps elsewhere, the high backscatter depressions are linked directly to the underlying substrate. Therefore at least in this case, these features cannot be equated with the “ripple scour depressions” as discussed by Cachionne et al. (1984) but have a different association with underlying topography. It is possible however that erosion of these features may be enhanced in this area by scouring around the topographic highs, and or sediment transport controlled or modified by these features in such a way to exaggerate the bathymetric expression of the underlying features. In this case, the scour is due to increase wave energy stress related to the topography. In this way there may be a looser genetic association with the ripple scour depressions described elsewhere. In any case, this apparent linkage between surface and subsurface features suggests somewhat less temporal and therefore volumetric mobility of the surficial sand sheet that would be expected if the scours were randomly generated during individual storm events, at least in the water depths in the study area, 45-75 m. The larger asymmetric highs are generally similar in form to sand waves, and similar in orientation to the overlying smaller sand waves, yet their wavelengths (200-600 m) are very large for this type of environment. We

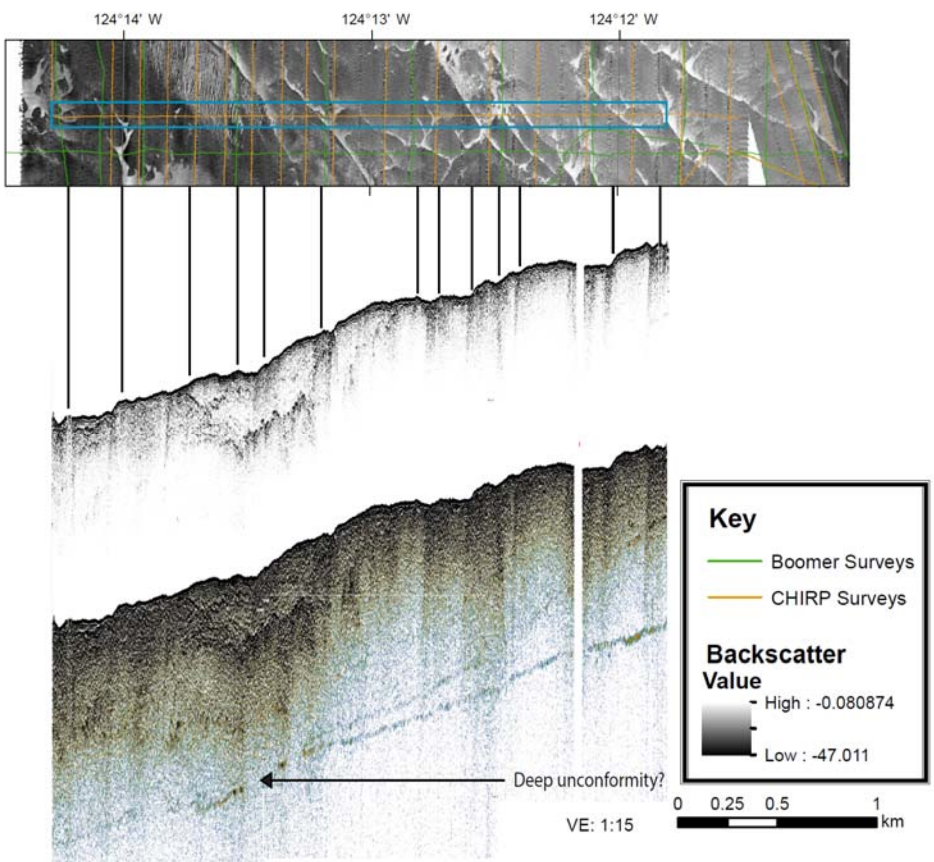


Figure 16. CHIRP profile and corresponding backscatter across possible paleo-dunes, SETS area.
Tie line between backscatter and profile are shown. Lower panel shows profile optimized to show deeper possible unconformity surface (this potentially also could be an artifact).

know of no modern analog on the PNW shelf where such features are forming today. As these features appear inactive, and without a modern submarine analog, we suspect that they may in fact be Pleistocene subaerial features that are now partly exposed and being overlain and modified by recent marine processes. Candidate features that could fit this description are very large subaerial dunes such as those observed between Florence and Coos Bay today along the modern coast. The dunes of the southern Oregon coast are similar in scale, and at least some areas have a NW orientation (Figure 17 and Figure 18), though E-W and SW trends are also seen in the same region. Dunes of that orientation have a much smaller wavelength and have a NW gentle face, consistent with summer N-NW winds. Dunes generally form with the gentle face on the upwind side (Figure 17). The asymmetry of the dunes observed on the southern Oregon coast (near Winchester OR) with a NW strike is with the gentle face facing SW, the predominant storm wind direction. The possible relict dunes in the SETS area have the opposite orientation, with the gentle face on the NE side, suggesting prevailing NE winds, very different from seasonal prevailing winds today.

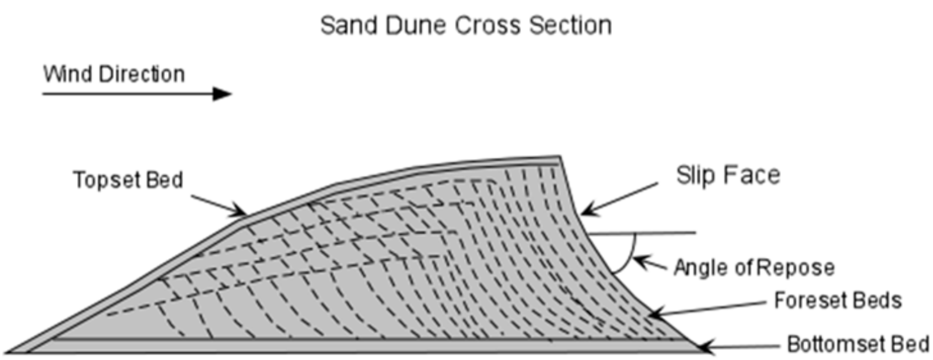


Figure 17. Typical subaerial dune cross section.
http://www.tulane.edu/~sanelson/images/dune.gif

Figure 18. Dune field south of Winchester, OR.
These dunes are roughly the same scale as the interpreted paleo-dunes on the SETS and BOEM study areas, having wavelengths of ~ 300-400 m (other nearby dune filed have much shorter wavelengths). The wind direction indicated by these dunes is northerly, while the offshore possible paleo-dunes suggest a northeasterly prevailing wind.

Subsurface Topography

The CHIRP and boomer seismic profiles reveal a complex shallow subsurface topography that is for the most part not apparent in the surface topography (Figure 19). In addition to the pervasive NW trending "paleo-dunes" and probably modern sand waves observed at the surface, the shallow subsurface (< ~20 m) is characterized by a generally irregular and commonly rough surface defined by several prominent reflectors in the sub-bottom profiles. We used the IHS Kingdom seismic interpretation package to integrate the SEGY seismic data from the boomer and CHIRP surveys with bathymetric and backscatter data for interpretation. We interpret 2-5 (typically 3) significant subsurface reflectors traced throughout the study area that we have used to track the variability of what are most likely old erosion surfaces. A planned vibra-coring survey was not successful in ground-truthing the sub bottom data, thus the following discussion lacks definitive ground truth regarding the lithology, hardness or age of the stratigraphic sequence. Figure 19 shows the high degree of subsurface topography apparent in much of the study area.

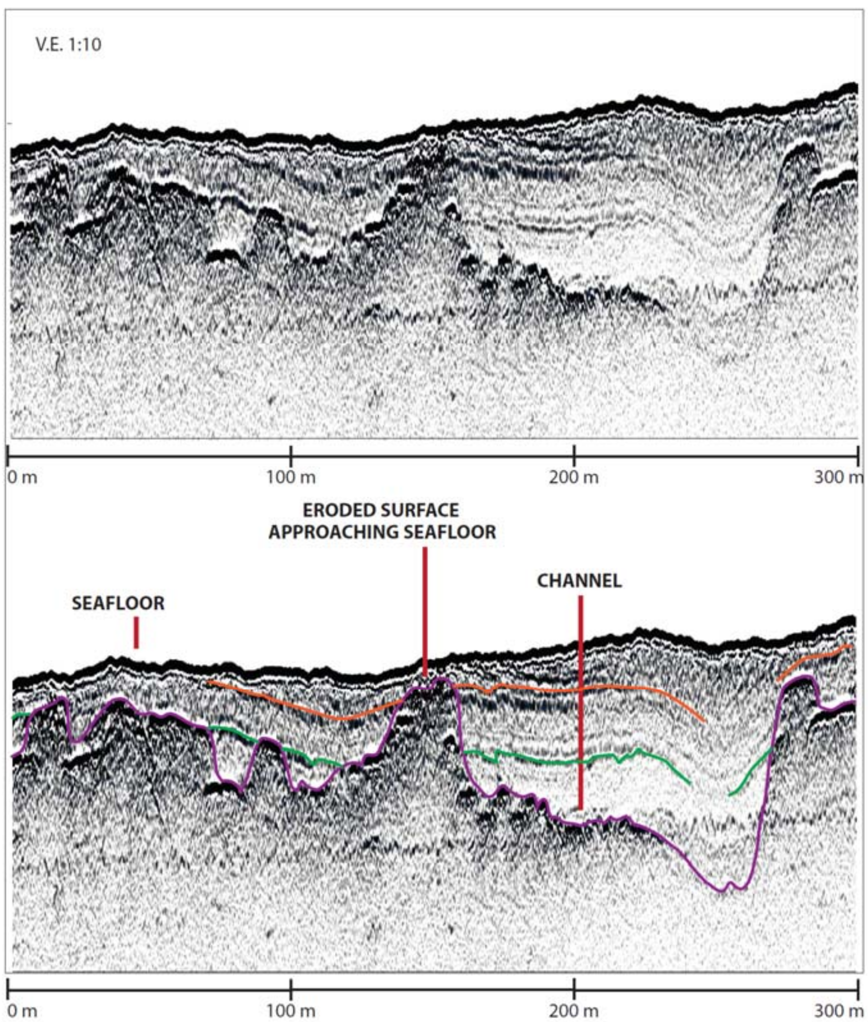


Figure 19. CHIRP profile, SETS area
This profile shows the subsurface paleo-topographic surface, a buried channel, and overlying transgressive sand cover in the SETS area.

While it was known or surmised that a transgressive gravel sheet existed in the subsurface, and it is presumed that a subaerial topography drowned after the LGM transgression existed, these data are among the first to show this surface in detail in the region. In the SETS area we observe what are most likely former stream channels associated with the modern Beaver Creek, the Alsea River and Yaquina River Channels. While not enough data exist to definitively connect the mapped channels with these modern systems, they positions and trends are highly suggestive of such a connection. The former channels are now filled with probable transgressive and post-transgression sediments. In addition to the channels, the uppermost hard reflector, here interpreted as the transgressive surface in most cases, has significant topography that may have been the pre-transgression land surface, likely modified as it

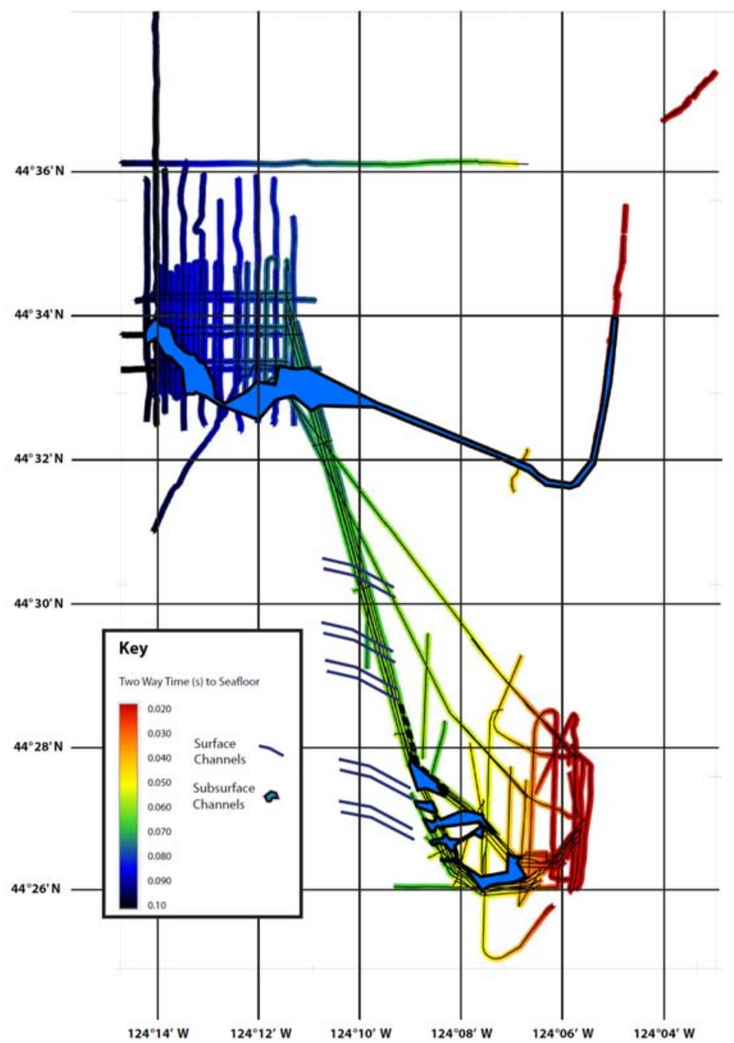


Figure 20. Two-way travel time to shallowest unconformity surface, SETS area
This colored surface represents the depth (in two way travel-time) to the first and most prominent unconformity surface thought to represent the now buried Pleistocene land surface. Buried channels also shown, in blue.

passed through the surf zone during rapid inundation of the latest Pleistocene meltwater pulses. Not enough data exist to map the surface in great detail, but the depth to the youngest surface (in two-way travel time) where enough data exist is shown in Figure 20 along with interpreted subsurface paleo-channels. This surface merges with the seafloor reflector in many places. In such cases we are unable to determine whether the surface reaches the seafloor or is thinly covered in some places, though in others this surface merges with the seafloor in the area of possible relict dunes. The shallow subsurface imaged in the SETS study resembles that described onshore where under high-stand conditions, Pleistocene sand filled channels and low spots cut into the Astoria Formation and Nye mudstones and are now exposed in the Newport area (Snavely et al., 1969). Without additional geophysical data we cannon know with certainty that the rough paleo surfaces observed at the SETS area are typical of the Oregon inner shelf, or in somewhat anomalous. We know of no particular reason, however, to suspect that this particular site is anomalous and think in more likely that it is relatively typical of the mid to inner continental shelf of at least the central Oregon margin.

Geologic Overview of the Route Options

Beaver Creek/Airport

The Beaver Creek Route was our initial target given this route had the shortest line mile path to the SETS area. We had expected that the main issue for this route could be the exposure or shallow subsurface existence of Columbia River basalt dikes or sills that were visually interpreted at the inboard (landward) end of the paleo-channel. Although the Beaver Creek paleo-channel through the Seal Rock anticline/reef complex looked to be a strong possibility for cable routing and burial, our initial sub bottom line along this route showed that sediment fill in the paleo-channel was very thin to non-existent, adding to the existing issue of Columbia River basalt occurrence along the route. Due to the apparent lack of potential for this route, other alternatives were extensively explored.

Driftwood and Alternates 1 and 2

We explored four other routes to the south of the beaver Creek Route, these are known as Driftwood Alternates 1-4. A northern route passing across the northern part of the Seal Rock anticline and reef complex was considered not viable due to extensive crossing of exposed rocky ridges. The other four Driftwood alternate routes explored areas to the south with increasing distance from Beaver Creek (Figure 21). The routes attempted to take advantage of the southward plunge of the Seal Rock Anticline in order to avoid exposures of hard substrates. Driftwood Alternates 1-2 consisted of single sub bottom lines trending to the southeast along paths laid out to avoid other apparent obstacles, mainly in the form of exposed gravel patches and shallowly buried or exposed bedrock outcrops. While at sea, monitoring of the incoming data revealed that these two routes had numerous incidences of shallowly buried subsurface topography that were not previously known. The extent and roughness of this topography were deemed sufficient to explore routes even further to the south, Driftwood Alternates 3 and 4.

Driftwood Alternates 3 and 4

Because the original routes and southern alternates 1 and 2 proved problematic, third and fourth alternates were explored south of the more northerly Driftwood alternates. Alternate 3 was a clear improvement over Alternates 1 and 2, at the expense of greater distance. Examination of the A3 wing line, bathymetric and backscatter data suggested that the geologic barriers to the more northerly routes might be mitigated by extending the survey still further to the south. The Driftwood A4 route indeed appears to pass to the south of the structural complex that lies in the path of the other Driftwood and alternate routes. A number of additional chirp and boomer lines were run in the in the southwestern part of the A4 Route (aka the "elbow") area to densify the data coverage there to test this potentially successful route in more detail.

Although this route appears to be the most favorable geologically, it nonetheless has potential near surface subcrops or outcrops of potentially older more indurated material. Several examples of these areas are shown on Figure 16 and Figure 19. Potential surficial gravel patches are further shown in the backscatter image in Figure 22. The remainder of the route west and north of the elbow area is relatively clear, with only few areas of modest probability of indurated materials in the near surface.

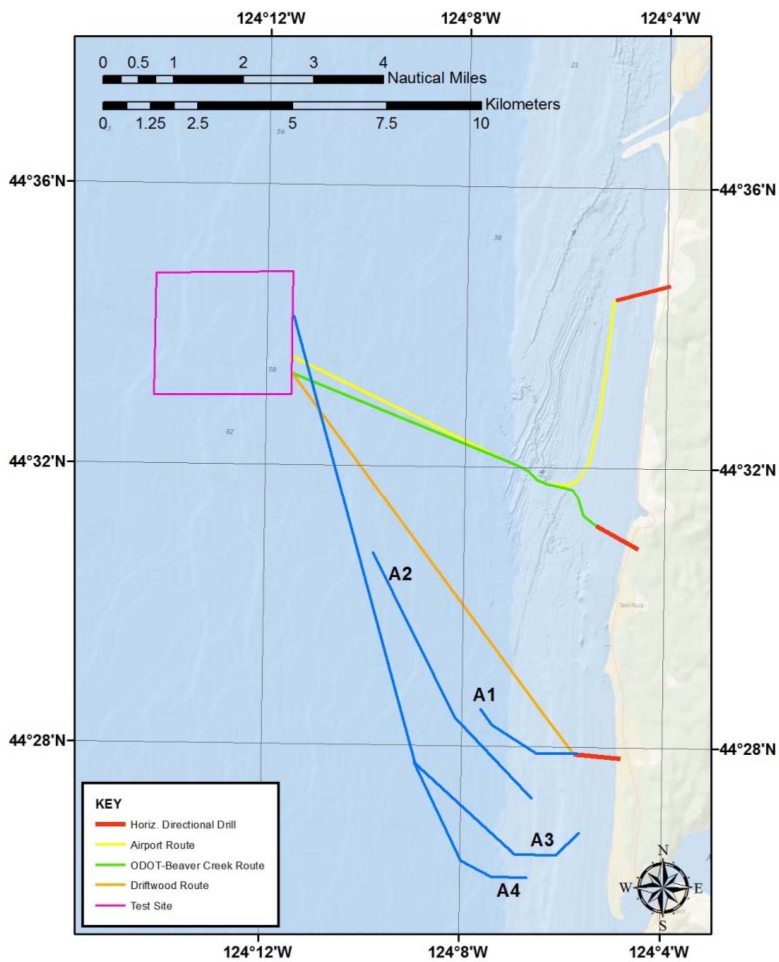


Figure 21. Alternate routes developed during the survey.

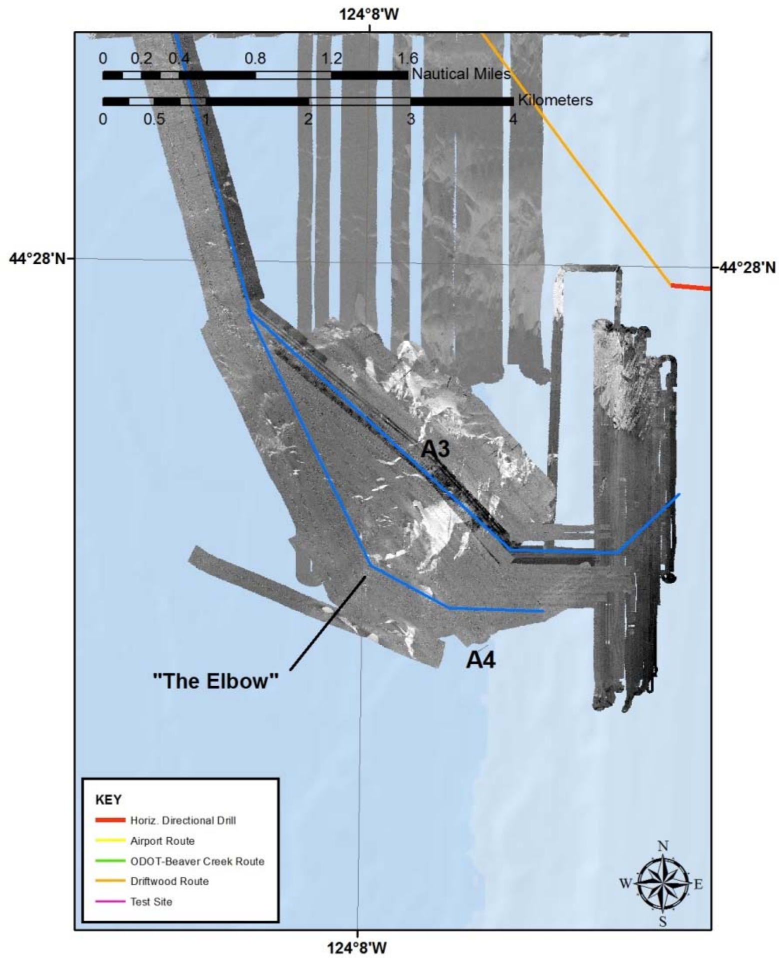


Figure 22. Backscatter imagery at "the elbow" along route alternates A3 and A4.

SETS Area

The geology of the Sets area has been described in previous sections as dominated by what we now interpreted as an extensive field of paleo-dunes. The height of the eroded dunes today is 1-5 m, typically 2-3 m, with wavelengths of 100-400 m. In the swales between the dunes the backscatter data and limited core data suggest fine sand to silt fill the low areas (Figure 23). The dunes themselves are likely composed of medium to coarse sand and may be partly indurated. The steeper faces of the dunes are eroded in dendritic and formless patterns that expose material of high backscatter 0.5-1 m below the surface of the dunes. The high backscatter material is mostly likely the ubiquitous transgressive gravel lag deposit encountered in numerous localities nearby. In the southern part of the SETS area, the dunes gradually give way to sandy surface substrate formed into short wavelength low-amplitude sand waves that may represent active sediment transport.

Figure 23. Sediment classification at the SETS area.

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